Predictability of Particle Trajectories in the Ocean

Tamay M. Ozgokmen
Division of Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science
4600 Rickenbacker Causeway
Miami, FL 33149
phone: (305) 361 4053 fax: (305) 361 4696 email: tozgokmen@rsmas.miami.edu

Annalisa Griffa
phone: (305) 361 4816 fax: (305) 361 4696 email: agriffa@rsmas.miami.edu

Arthur Mariano
phone: (305) 361 4193 fax: (305) 361 4696 email: amariano@rsmas.miami.edu

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LONG-TERM GOALS

The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, floating mine problems, design of observing systems and development of navigation algorithms.

OBJECTIVES

The specific scientific objective of the work done has been to determine the effectiveness of using in-situ Lagrangian measurements and data assimilation techniques in improving the prediction of particle trajectories.

APPROACH

The work is based primarily on stochastic models of particle motion and data assimilation strategies. It also involves the use of ocean general circulation models and processing of oceanic data such as drifter positions, ocean surface currents, and wind field.

WORK COMPLETED

1) Publication of a review paper summarizing the Lagrangian research results presented in LAPCOD (Lagrangian Analysis and Predictability of Coastal and Oceanic Dynamics) 2000 workshop. This paper is published in the Journal of Atmospheric and Oceanic Technology (Mariano et al., 2002).
2) Organization of the second LAPCOD workshop in December 2002, which was attended by some 70 international scientists. The PIs of this grant are presently pursuing publication of a book on Lagrangian dynamics (the first of its kind, to our knowledge) with several workshop attendees. The book will be edited by the PIs, T. Rossby and D. Kirwan.

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14. ABSTRACT
The long term goal of this project is to determine optimal sampling strategies for drifting buoys, in order to enhance prediction of particle motion in the ocean, with potential applications to ecological, search and rescue, floating mine problems, design of observing systems and development of navigation algorithms.

15. SUBJECT TERMS

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3) Completion of the investigation of the impact of in-situ wind forcing on the reconstruction of drifter trajectories. This manuscript is accepted for publication in Journal of Atmospheric and Oceanic Technology (Paldor et al.).
4) Development of a new type of boundary condition based on stochastic modeling of submesoscale processes. This paper is published in Geophysical Research Letters (Mariano, Chin, Ozgokmen).
5) The use of cubic B-spline technique as a means of efficient interpolation and its application to data assimilation problems. This paper is in press in Journal of Atmospheric and Oceanic Technology (Chin, Ozgokmen, Mariano).
6) Investigation of the impact of uncertainty in the Eulerian flow field on the predictability of Lagrangian trajectories. This manuscript is submitted to Journal of Marine Research (Griffa, Piterbarg, Ozgokmen).
7) Design and construction of a 34 processor Beowulf parallel computer cluster for use in assimilation and prediction studies.

RESULTS

Stochastic boundary conditions for coastal flow modeling

Recent high-resolution radar data of surface velocity between the Florida Current and the coast allow us for the first time to deduce coastal boundary conditions for ocean models based on observations. Analysis of these observations indicates that a stochastic model is a better choice for simulating properties of the observed vorticity than a model with deterministic boundary conditions. A stochastic model parameterizing boundary conditions is developed and embedded in a simple quasigeostrophic ocean model. Comparison of numerical simulations of western boundary flow with stochastic boundary conditions to simulations with traditional no-slip and free-slip conditions reveals significant differences in the formation of coherent mesoscale structures and the energetics of the western boundary current. In particular, different coherent structures, such as dipoles and submesoscale vortices, are simulated using stochastic boundary conditions, and the boundary current variability is more energetic and "episodic" compared to quasi-periodic circulation features in the simulations using conventional boundary conditions.

This paper is published in Geophysical Research Letters (Mariano, Chin, Ozgokmen, 2003).

Multi-variate spline solution for variational analyses

A recipe for a cubic B-spline based solution for multi-variate variational formulation of a data analysis and assimilation problem is provided. We show that, to represent a signal whose smallest wavelength is L, the spline-scale must be at most L/2 or approximately the Nyquist wavelength. This spline-scale defines the computational grid, which tends to be coarser than the typical grid required for finite-difference discretization and hence offers a significant advantage in computational efficiency. The geostrophy-thinplate model is introduced and applied to a set of analysis problems to demonstrate the effectiveness of the solution technique.

This paper is in press in Journal of Atmospheric and Oceanic Technology (Chin, Ozgokmen, Mariano, 2003).

Effects of uncertainty in the Eulerian flow on Lagrangian particle trajectories

The increasing realism of ocean circulation models is leading to increasing use of these Eulerian models as basis to compute transport properties and to predict the fate of Lagrangian quantities. There exists, however, a significant gap between the spatial scales of model resolution and that of forces acting on Lagrangian particles. These scales may contain high vorticity coherent structures that are not resolved due to computational issues and/or missing dynamics but are typically suppressed by smoothing operators.

In this study, the impact of smoothing of the Eulerian fields on the predictability of Lagrangian particles is first investigated by conducting twin experiments that involve release of clusters of synthetic Lagrangian particles into "true" (unmodified) and "model" (smoothed) Eulerian fields, which are generated by a highly nonlinear QG model (Fig. 1). The Lagrangian errors induced by Eulerian smoothing errors are quantified by using two metrics, the difference between the centers of mass of particle clusters, r, and the difference between scattering of particles around the center of mass, s. The results from QG experiments show that even minute changes in the flow field induce significant errors in r, whereas s errors are much lower.

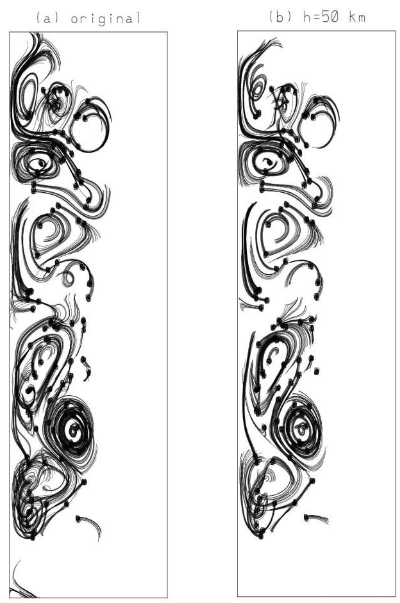

***Figure 1: Samples of 15 day long Lagrangian trajectories from clusters released in (a) the original flow field, and (b) the smoothed Eulerian flow fiel*d.**

The QG results are then compared to results obtained from a multi-particle Lagrangian Stochastic Model (LSM) which parameterizes turbulent flow using main flow characteristics such as mean flow, velocity variance and Lagrangian time scale. In addition to numerical results, also theoretical results based on the LSM are considered, providing asymptotics of r,s and predictability time. It is shown that both numerical and theoretical LSM results provide a good qualitative description, and a reasonable first-order quantitative estimate of results from QG experiments (Fig. 2). Given estimates of several

observable parameters, and the simplicity of implementation, the multi-particle LSM therefore appears to be a promising avenue to provide guidelines for predictability estimates in realistic ocean flows.

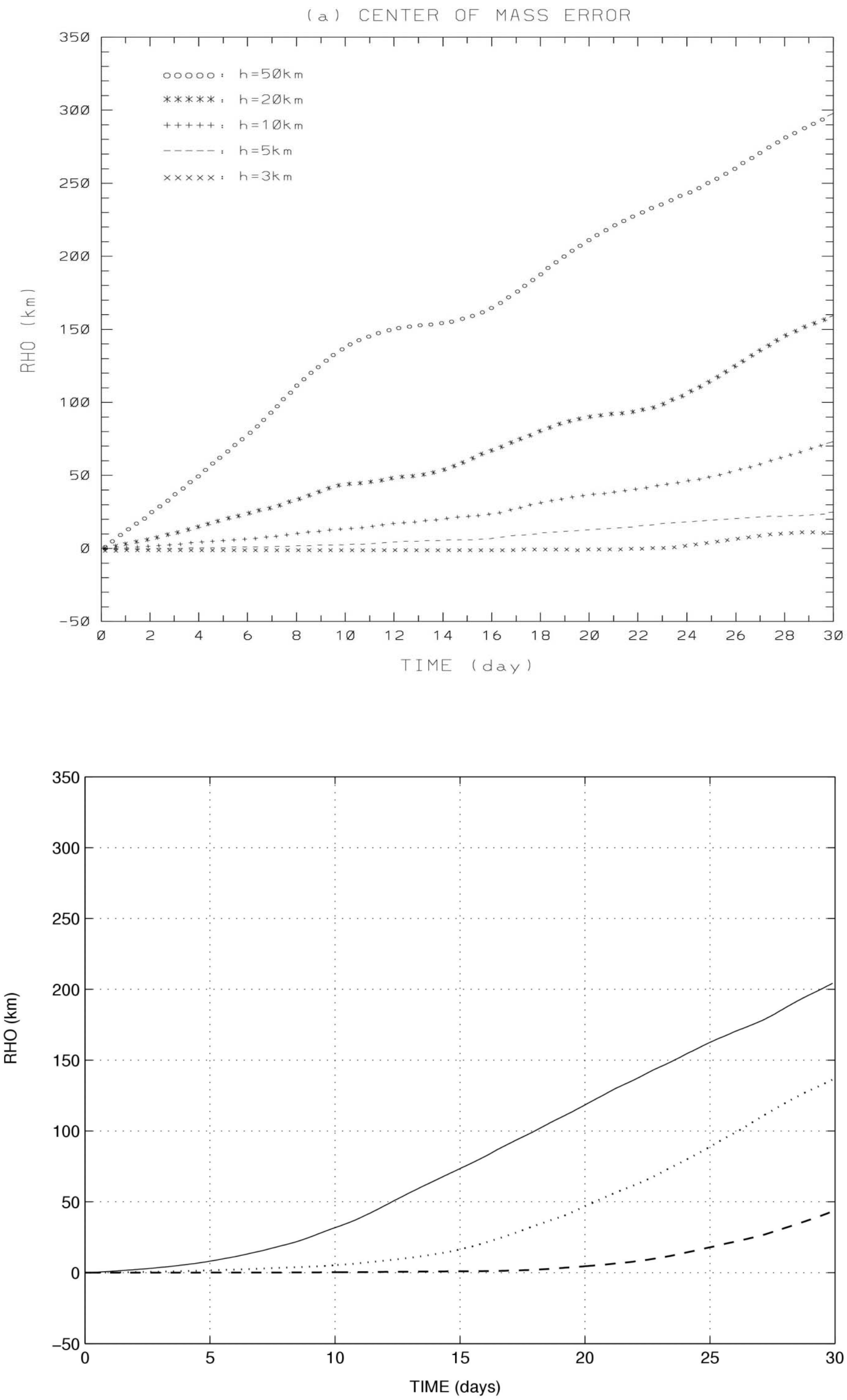

Figure 2: (Upper panel) Center of mass error as a function of the smoothing parameter h from particles releases in QG experiments. (Lower panel) Results from multi-particle Lagrangian stochastic model.

IMPACT/APPLICATIONS

The investigation of the predictability of particle motion is an important area of study, with a number of potential practical applications at very different scales, including searching for persons or valuable objects lost at sea, tracking floating mines, ecological problems such as the spreading of pollutants or fish larvae, design of observing systems and navigation algorithms.

PUBLICATIONS (2002-2003)

Refereed publications:

Piterbarg, L.I., and T.M. Ozgokmen, 2002: A simple prediction algorithm for the Lagrangian motion in 2D turbulent flows. SIAM *J. Appl. Math*., 63, 116-148.

Mariano, A.J., A. Griffa, T.M. Ozgokmen, and E. Zambianchi, 2002: Lagrangian Analysis and Predictability of Coastal and Ocean Dynamics 2000. *J. Atmos. Ocean. Tech*., 19/7, 1114-1126.

Mariano, A.J., T.M. Chin, and T.M. Ozgokmen, 2003: Stochastic boundary conditions for coastal flow modeling. Geophys. Res. Letters, 30/9, doi:10.1029/2003GL016972.

Chin, T.M., T.M. Ozgokmen, and A.J. Mariano, 2003: Multi-variate spline and scale-specific solution for variational analyses. *J. Ocean. Atmos. Tech*., accepted.

Paldor, N., Y. Dvorkin, A.J. Mariano, T.M. Ozgokmen, and E. Ryan, 2003: Reconstruction of near-surface drifter trajectories in the Pacific Ocean with a hybrid model. *J. Atmos. Ocean Tech*., accepted.

Griffa, A., L.I. Piterbarg, and T.M. Ozgokmen: Predictability of Lagrangian trajectories: effects of uncertainty in the underlying Eulerian flow. *J. Mar. Res*., submitted.

Piterbarg, L.I., T.M. Ozgokmen, A. Griffa, and A.J. Mariano: Predictability of Lagrangian motion in the upper ocean. Submitted for review for LAPCOD book.